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Considering fairness preference in the supply chain carbon emissions decision analysis

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***Abstract*—Under linear demand conditions, assuming there is a two-echelon supply chain carbon emission reduction system composed of a supplier and a retailer, we introduce the Nash Bargaining fair Solution into the model, engage in case studies to examine the supplier's optimal wholesale price and his optimal carbon emission reduction as well as the retailer's optimal retail price. For that reason, we consider three different cases such as the retailer having fairness preference, the supplier having the fairness preference and both of them enjoying fairness preference at the same time. The study found out that both supplier's wholesale price and retailer's sales price are affected either by their own fairness preference or by that of the other party, more important in the game the supplier will not actively take the initiative to reduce carbon emissions since the volume will progressively decrease as a supply chain entity's fairness preference degree increases.**

***Key words* —supply chain; carbon emission; fairness preference; Nash bargaining**

I. INTRODUCTION

Faced with an increasingly serious problem of global warming, reduce carbon dioxide emissions has become a consensus of the international community. However, the current situation about carbon emissions is not satisfactory; according to the United Nations Environment Program (UNEP) "Emissions gas report" published in 2013, the world total carbon dioxide emissions volume should not exceed 44 billion tons by 2020. Yet, the data has reached 50.1 billion tons in 2010 and if this issue is not controlled, it is expected to reach 590 million tons by 2020. Therefore, we are urged to take further measures to reduce carbon dioxide emissions. Faced such a serious situation, all countries are seeking cooperation to address common problems facing mankind, and representatives from 195 countries as well as from the European Union attended the 21st UN General Assembly on Climate Change in Paris, France, and finally reached a new global climate agreement. "The Paris agreement" points out that countries would not only strengthen the global response to the threat of climate change, control the global average temperature rise comparatively with pre-industrial levels within 2 degrees Celsius, but also take measures to control the temperature rise level within 1.5 degrees Celsius. Besides, the agreement stipulates that the different parties would have to participate in the global action on responding to climate change in a "self-contribution" way. Developed countries will continue to take the lead in emissions reduction, provide capital, technology and capacity building to support developing countries to mitigate and adapt to climate change. China as a responsible developed country, early by the eve of the 2009 Climate Change Conference in Copenhagen, has made a responsible commitment to the world: by 2020, China's carbon dioxide emissions percentage in its unit GDP will reduce 40% - 45% compared to 2005.

La Roche et al pointed out that more and more consumers are conscious of the importance of green consumption and wish to buy green products, even at a higher cost [1]. Li et al argued that in a new mode of economic growth, people during shopping give priority to goods produced under environmental protection regulations. Therefore, the study of decisions on the supply chain carbon emissions reduction is of high significance for enterprises [2].

Choi et al studied the problem of the supply chain pricing game based on a two-echelon supply chain made up of two suppliers and a retailer [3]. Zhang et al discussed the

single-cycle green supply chain pricing decisions and coordination problems under the coexistence of non-green products and green products market demand[4].Xu et al based on the game theory, studied the decision making problem in a closed loop supply chain where the supplier is in the dominant position[5]. Qian et al studied in the case of decentralized decision making, the optimal ordering policy and pricing decision problem on the basis of a supply chain system which consists of one manufacturer and two retailers [6]. Wang et al studied the problem of optimal decision making, when the market demand is affected by price and advertisement investment, on a supply chain composed of traditional retail channels and direct sales channels [7].

Benjaafar et al considered the factors affecting carbon emission reduction in the supply chain system, and studied the low carbon supply chain operation [8]. Zhang et al based on the newsboy model, studied the optimal production strategy under the constraint of carbon emissions [9]. Jaber et al studied the problem of cooperation between supply chain members in the case of a carbon transaction [10]. Zhang et al studied yield, pricing and profits issues under different cooperation mechanisms on the basis of a three-level supply chain [11]. Song et al based on the newsboy model discussed the mandatory emission reductions, carbon taxes and the total amount restriction impacts on the optimal decision [12].Wang investigated the optimal contracts and the manufacturer's pricing strategies based on a supply chain consisted of a single-manufacturer and single-retailer [13]. Li et al took a two-echelon supply chain system as research object to discuss the impact of the carbon tax policy on the decisions of the supply chain companies [14].

Some behavioral economists show that decision makers tend to have fairness preference, and while thinking about their own interests, the decision makers would also focus on an equitable distribution of benefits, and fairness preference can affect decision-making behavior of the economic entity [15]. Cui et al studied the effect of fairness preference on the coordination of supply chain when there is certainty in the demand [16]. Wei et al discussed optimal pricing strategies in a dual-channel supply chain with fairness preference and risk aversion [17]. In the case of nonlinear demand, Caliskan–Demirag discussed the effect of fairness preference on the coordination of the supply chain when one of the main body of the chain has fairness preference [18]. Ho et al studied the effects of different types of fairness preference on a supply chain system based on a chain composed of one supplier and two retailers [19]. Under a non-linear demand constraint, Wei et al used fairness preference theory to study the problem of the coordination of supply chain [20]. Zhang et al used the game theory to analyze corresponding pricing decision models, and studied the closed-loop supply chain pricing considering fairness concerns behavior decision-making [21]. On the basic of Stackelberg theory, researchers studied the impact of the fairness concern on the supply chain subjects' decision-making when retailers and suppliers have fair concern [22].

Currently, several research articles have discussed about fairness from the equitable allocation of carbon emissions rights and carbon emissions trading fairness aspects. Haddad et al compared the cap-and-trade model with the greenhouse gas emissions trading reduction model based on applicability and fairness criteria [23]. Onigkeit et al studied the carbon trading system considering fairness factors [24]. Zhang et al studied efficiency and fairness in Chinese provinces carbon emission rights allocation problems [25]. Zhao studied the problem of international aviation carbon emissions rights fair allocation. Based on the responsibility principle, Zhao advanced a method for fair

allocation of international aviation emissions rights [26].

The main issues discussed in the articles mentioned above are fair distribution and transaction from a general aspect. However, fairness in the supply chain is very different. It is mainly about fairness is what is gained after comparison with another subject of the supply chain or oneself; few papers have been published about carbon emissions and fairness preference in the supply chain. Li et al in a low-carbon environment, studied the influence of different agreements on the supply chain coordination when retailers have fairness preferences, and especially the issue of pricing agreement when the supplier has fairness preferences [27]–[28]. Based on the case where the supplier has the fairness preference, Lin studied the influence on the supply chain members pricing decisions and on emission reduction level [29].

On the basis of the above documents, this paper considers a supplier carrying carbon emissions reduction, explores the effect of fairness preference coefficient on the decisions of supply chain members in three different cases such as the supplier with fairness preference, the retailer with fairness preference and both supplier and retailer having fairness preferences at the same time by using the Nash bargaining fair solution.

II. PROBLEM DESCRIPTION AND HYPOTHESIS

A. The supply chain consists of a supplier s and a retailer r. c represents the Unit Production Cost of the supplier. w represents the wholesale price of the supplier. p represents the retailer's sales price with $p > w > c > 0$

B. The market demand is a linear function $D = a - bp + \delta e$,a represents the basic market demand, b represents the price impact's coefficient, e represents the unit product carbon emission reduction, δ represents the carbon emission reduction effect coefficient, with $a > 0, b > 0, \delta > 0$, $e \geq 0$.

C. The supplier's carbon emission reduction cost is $\frac{\eta e^2}{2}$,and the carbon emission reduction cost coefficient is $\eta\,(\eta > 0)$.

D. The retailer's profit function is $\pi_r = (p-w)(a-bp+\delta e)$; the supplier's profit function is $\pi_s = (w-c)(a-bp+\delta e) - \frac{\eta e^2}{2}$; and the supply chain profit function is $\pi = (p-c)(a-bp+\delta e) - \frac{\eta e^2}{2}$.

E. The subscript rn represents only the retailer with fairness preference. The subscript sn represents only the supplier with fairness preference. The subscript bn represents both retailers and suppliers with fairness preference at the same time. The superscript $*$ represents the optimal solution.

III. THE SUPPLY CHAIN SUBJECTS DO NOT HAVE FAIRNESS PREFERENCE

When the supply chain subjects do not have fairness preference, it is applied between the supplier and the retailer a Stackelberg game, the supplier decides his wholesale price and the quantity of carbon emission reductions before the retailer decides his sales price. The purpose of the supplier's and retailer's decision is to maximize their profit. Using the inverse method, the first derivative and the second derivative of the retailer's profit function are as following:

$$\frac{\partial \pi_r}{\partial p} = -2bp + bw + \delta e + a\,,\ \frac{\partial^2 \pi_r}{\partial p^2} = -2b$$

$\frac{\partial^2 \pi_r}{\partial p^2} < 0$, the retailer has the optimal

pricing p

When $\frac{\partial \pi_r}{\partial p}=0$,

$$p=\frac{\mathrm{bw}+\delta\mathrm{e}+\mathrm{a}}{2\mathrm{b}} \quad (1)$$

Replacing (1) in π_s, we obtain the first derivative and the second derivative of the supplier's profit function.

$$\frac{\partial \pi_s}{\partial w}=\frac{1}{2}\mathrm{bc}-bw-\frac{1}{2}\delta\mathrm{e}+\frac{1}{2}\mathrm{a}\ ,\ \frac{\partial^2 \pi_s}{\partial w^2}=-b$$

$\frac{\partial^2 \pi_s}{\partial w^2}<0$, the supplier has the optimal pricing w

When $\frac{\partial \pi_s}{\partial w}=0$,

$$\mathrm{w}=\frac{\mathrm{bc}+\delta\mathrm{e}+\mathrm{a}}{2\mathrm{b}} \quad (2)$$

$$\frac{\partial \pi_s}{\partial e}=-\frac{1}{2}\mathrm{c}\delta+\frac{1}{2}\mathrm{w}\delta-\eta\mathrm{e}\ ,\ \frac{\partial^2 \pi_s}{\partial e^2}=-\eta$$

$\frac{\partial^2 \pi_s}{\partial e^2}<0$, the supplier has the best carbon emissions e

When $\frac{\partial \pi_s}{\partial e}=0$,

$$e=\frac{\delta(w-c)}{2\eta} \quad (3)$$

From (2) and (3) are obtained the optimal wholesale price of the supplier and the optimal carbon emission reduction:

$$w^*=\frac{2bc\eta-c\delta^2+2a\eta}{4b\eta-\delta^2} \quad (4)$$

$$e^*=\frac{\delta(a-bc)}{4b\eta-\delta^2} \quad (5)$$

Introduce (4) (5) into (1), to obtain the optimal price of retailer,

$$p^*=\frac{bc\eta-c\delta^2+3a\eta}{4b\eta-\delta^2}$$

Because $p^*>\mathrm{w}^*>\mathrm{c}>0$, $e^*>0$, and the market demand being very high, without loss of generality, so $4b\eta-\delta^2$ Should be greater than 0.

IV. NASH BARGAINING FAIR SOLUTION

Indeed, fairness has relative characteristics, the strength and contribution of the supply chain members affect fairness in profit distribution. So, the use of the Nash bargaining fair solution considering the strength or the contribution of the members of the supply chain reflects fairness relativity, and discredit previous researches about fairness in the supply chain that consider absolute fairness limitations.

In this paper, Nash bargaining fair solution is introduced as a reference solution helping the supply chain subjects to perceive fairness. Assuming the fair solution of Nash bargaining is $\overline{\pi_r}$ and $\overline{\pi_s}$, according to the literature [30] when the supply chain subjects have fairness preference, the utility function of the supply chain subjects is

$$U_r=\pi_r+\lambda_r(\pi_r-\overline{\pi_r})=(1+\lambda_r)\pi_r-\lambda_r\overline{\pi_r}$$

$$U_s=\pi_s+\lambda_s(\pi_s-\overline{\pi_s})=(1+\lambda_s)\pi_s-\lambda_s\overline{\pi_s}$$

$$U=U_r+U_s$$

The fair solution for retailers and suppliers is then

$$\overline{\pi_r}=\frac{1+\lambda_r}{2+\lambda_r+\lambda_s}\pi$$

$$\overline{\pi_s}=\frac{1+\lambda_s}{2+\lambda_s+\lambda_r}\pi$$

V. CONSIDERING ONLY THE RETAILER HAVING FAIRNESS PREFERENCE

When only the retailer has fairness preference, $\lambda_s=0$. His utility function is then

$$U_r=(1+\lambda_r)\pi_r-\frac{\lambda_r(1+\lambda_r)}{2+\lambda_r}\pi$$
$$=(1+\lambda_r)(p-w)(a-bp+\delta e)$$
$$-\frac{\lambda_r(1+\lambda_r)}{2+\lambda_r}\left[(p-c)(a-bp+\delta e)-\frac{1}{2}\eta e^2\right]$$

The supplier does not have fairness preference, so the supplier's utility function is $U_s=\pi_s$

Proposition 1: When only the retailer has

fairness preference, the retailer's utility function and the supplier's utility function are strictly concave functions, the best price p_{rn}^* of the retailer drives U_r get the maximum value ,and $p_{rn}^* = \frac{bc\eta\lambda_r + 3a\eta\lambda_r + 2bc\eta - 2c\delta^2 + 6a\eta}{2(2b\eta\lambda_r + 4b\eta - \delta^2)}$. The supplier's optimal wholesale price and optimal carbon emission reduction which are respectively w_{rn}^* and e_{rn}^* drive Us value to the maximum and $w_{rn}^* = \frac{2bc\eta\lambda_r + 2bc\eta - c\delta^2 + 2a\eta}{2b\eta\lambda_r + 4b\eta - \delta^2}$, $e_{rn}^* = \frac{(a-bc)\delta}{2b\eta\lambda_r + 4b\eta - \delta^2}$。

Proof: The first derivative and the second derivative of the U_r

$$\frac{\partial U_r}{\partial p} = (1+\lambda_r)(-bp+\delta e+a) - (1+\lambda_r)(p-w)b - \frac{\lambda_r(1+\lambda_r)(-bp+\delta e+a-(p-c)b)}{2+\lambda_r}$$

$\frac{\partial^2 U_r}{\partial p^2} < 0$ U_r is a strictly concave function, and the retailer has the best price.

When $\frac{\partial U_r}{\partial p} = 0$,

$$p_{rn} = \frac{-bc\lambda_r + bw\lambda_r + 2bw + 2\delta e + 2a}{4b} \quad (6)$$

If we replace (6) in U_s, we will get a function as follows.

$$U_s = (w-c)\left[\frac{1}{4}b\lambda_r(c-w) - \frac{1}{2}(wb+\delta e+a)\right] - \frac{1}{2}\eta e^2$$

The first derivative and the second derivative of U_s are

$$\frac{\partial^2 U_s}{\partial w^2} < 0, \frac{\partial^2 U_s}{\partial e^2} = -\eta < 0$$

U_s is a strictly concave function, the supplier can get the best wholesale price and the optimal carbon emission reduction.

When $\frac{\partial U_s}{\partial w} = 0$,

$$w = \frac{bc\lambda_r + bc + \delta e + a}{b(2+\lambda_r)} \quad (7)$$

When $\frac{\partial U_s}{\partial e} = 0$,

$$e = \frac{(w-c)\delta}{2\eta} \quad (8)$$

Respectively (7) (8), the optimal wholesale price and the optimal carbon reduction are obtained when the retailer has fairness preference.

$$w_{rn}^* = \frac{2bc\eta\lambda_r + 2bc\eta - c\delta^2 + 2a\eta}{2b\eta\lambda_r + 4b\eta - \delta^2} \quad (9)$$

$$e_{rn}^* = \frac{(a-bc)\delta}{2b\eta\lambda_r + 4b\eta - \delta^2} \quad (10)$$

Introduce (9) (10) into (6), the optimal retail price of retailer are obtained when the retailer has fairness preference.

$$p_{rn}^* = \frac{bc\eta\lambda_r + 3a\eta\lambda_r + 2bc\eta - 2c\delta^2 + 6a\eta}{2(2b\eta\lambda_r + 4b\eta - \delta^2)}$$

Completed.

Conclusion 1 $\frac{\partial w_{rn}^*}{\lambda_r} < 0$, $\frac{\partial e_{rn}^*}{\lambda_r} < 0$, $\frac{\partial p_{rn}^*}{\partial \lambda_r} < 0$

Prove: The partial derivative of w_{rn}^* on λ_r

$$\frac{\partial w_{rn}^*}{\lambda_r} = \frac{-4b\eta^2(a-bc)}{(2b\eta\lambda_r + 4b\eta - \delta^2)^2}$$

With $p > c$, so $a - bc > 0$

Obviously $\frac{\partial w_{rn}^*}{\lambda_r} < 0$

In the same way, the partial derivatives of e_{rn}^* and p_{rn}^* on λ_r are obtained.

$$\frac{\partial e_{rn}^*}{\lambda_r} = \frac{-2\delta b\eta(a-bc)}{(2b\eta\lambda_r + 4b\eta - \delta^2)^2}$$

$$\frac{\partial p_{rn}^*}{\partial \lambda_r} = \frac{-3\delta^2\eta(a-bc)}{2(2b\eta\lambda_r + 4b\eta - \delta^2)^2}$$

Obviously $\frac{\partial e_{rn}^*}{\lambda_r} < 0$, $\frac{\partial p_{rn}^*}{\partial \lambda_r} < 0$

Completed.

Conclusion 1 indicates that the supplier's wholesale price and carbon emission reduction are influenced by the retailer fairness preference degree and reduced with the increase of retailers'

fairness preference. As for the retailer's selling price, it decreases with the increase of his own fairness preference. It suggests that when the retailers has fairness concerns, the supplier reduces the wholesale price, transferring some of his profits. At the same time, due to the decrease of the wholesale price, the supplier will not take the initiative of emission reduction, so as to reduce cost, while retailers would lower their selling prices to expand the demand for commodities, and to ensure the supply chain members fair profit distribution.

VI. CONSIDERING ONLY THE SUPPLIER HAVING FAIRNESS PREFERENCE

When we consider that only the supplier has fairness preference, $\lambda_r = 0$, the utility function of the retailer is $U_r = \pi_r$, the utility function of the supplier $U_s = (1+\lambda_s)\pi_s - \frac{\lambda_s(1+\lambda_s)}{2+\lambda_s}\pi$

$$= (1+\lambda_s)\left[(w-c)(a-bp+\delta e)-\frac{1}{2}\eta e^2\right]$$

$$-\frac{\lambda_s(1+\lambda_s)}{2+\lambda_s}\left[(p-c)(a-bp+\delta e)-\frac{1}{2}\eta e^2\right]$$

Proposition 2: When only the supplier has fairness preference, the utility functions of the retailer and the supplier are strictly concave functions, and the retailer's optimal price p_{rn}^* drives U_r value to the maximum ,and $p_{sn}^* = \frac{a\eta\lambda_s + bc\eta - c\delta^2 + 3a\eta}{b\eta\lambda_s + 4b\eta - \delta^2}$, The supplier's optimal wholesale price and optimal carbon emission reduction which are respectively w_{rn}^* and e_{rn}^* make of U_s value the maximum one, and

$$w_{sn}^* = \frac{a\eta\lambda_s + 2bc\eta - c\delta^2 + 2a\eta}{b\eta\lambda_s + 4b\eta - \delta^2},$$

$$e_{sn}^* = \frac{(a-bc)\delta}{b\eta\lambda_s + 4b\eta - \delta^2}.$$

Proof: the first derivative and the second derivative of U_r are:

$\frac{\partial^2 U_r}{\partial p^2} = \text{-2b} < 0$ U_r is a strictly concave function, and the retailer has the best price.

With $\frac{\partial U_r}{\partial p} = 0$,

$$p = \frac{\text{bw}+\delta\text{e+a}}{\text{2b}} \tag{11}$$

Introduce (11) into U_s , we obtain the first derivative and the second derivative of U_s .

$$\frac{\partial^2 U_s}{\partial w^2} = \frac{b(\lambda_s^2 + 5\lambda_s + 4)}{-2(2+\lambda_s)}$$

$$\frac{\partial^2 U_s}{\partial e^2} = \frac{\delta^2\lambda_s^2 + 4b\eta\lambda_s + \delta^2\lambda_s + 4b\eta}{-2(2+\lambda_s)b}$$

$$\frac{\partial^2 U_s}{\partial w^2} < 0, \frac{\partial^2 U_s}{\partial e^2} < 0$$

So U_s is a strictly concave function, the supplier can get the optimal wholesale price w and the optimal carbon emission reduction e when the supplier has fairness preference.

$\frac{\partial U_s}{\partial w} = 0$ and $\frac{\partial U_s}{\partial e} = 0$, the optimal wholesale price and the optimal carbon reduction are :

$$w_{sn}^* = \frac{a\eta\lambda_s + 2bc\eta - c\delta^2 + 2a\eta}{b\eta\lambda_s + 4b\eta - \delta^2} \tag{12}$$

$$e_{sn}^* = \frac{(a-bc)\delta}{b\eta\lambda_s + 4b\eta - \delta^2} \tag{13}$$

Introduce (12) (13) into (11), the optimal retail price of retailer are obtained when the retailer has fairness preference.

$$p_{sn}^* = \frac{a\eta\lambda_s + bc\eta - c\delta^2 + 3a\eta}{b\eta\lambda_s + 4b\eta - \delta^2}$$

Completed

Conclusion 2: $\frac{\partial e_{sn}^*}{\lambda_s} < 0$

When $\delta^2 < 2b\eta$, $\frac{\partial w_{sn}^*}{\partial\lambda_s} > 0$, when $2b\eta < \delta^2 < 4b\eta$, $\frac{\partial w_{sn}^*}{\partial\lambda_s} < 0$;

When $\delta^2 > b\eta$, $\frac{\partial p_{sn}^*}{\partial\lambda_s} < 0$,when $\delta^2 < b\eta$,

$\frac{\partial p_{sn}^{*}}{\partial \lambda_s} > 0$ 。

Prove: $\frac{\partial e_{sn}^{*}}{\lambda_s} = \frac{\delta\left(bc-a\right)b\eta}{\left(b\eta\lambda_s + 4b\eta - \delta^2\right)^2}$

Obviously $\frac{\partial e_{sn}^{*}}{\lambda_s} < 0$

$$\frac{\partial w_{sn}^{*}}{\partial \lambda_s} = \frac{-2b^2c\eta^2 + bc\delta^2\eta + 2ab\eta^2 - a\delta^2\eta}{\left(b\eta\lambda_s + 4b\eta - \delta^2\right)^2}$$

$$= \frac{\delta^2\eta(bc-a) + 2b\eta^2(a-bc)}{\left(b\eta\lambda_s + 4b\eta - \delta^2\right)^2} = \frac{(a-bc)\eta(2b\eta - \delta^2)}{\left(b\eta\lambda_s + 4b\eta - \delta^2\right)^2}$$

$$\frac{\partial p_{sn}^{*}}{\partial \lambda_s} = \frac{-b^2c\eta^2 + bc\delta^2\eta + ab\eta^2 - a\delta^2\eta}{\left(b\eta\lambda_s + 4b\eta - \delta^2\right)^2}$$

$$= \frac{\eta\left(a-bc\right)\left(b\eta - \delta^2\right)}{\left(b\eta\lambda_s + 4b\eta - \delta^2\right)^2}$$

although $4b\eta - \delta^2 > 0$,it cannot guarantee $2b\eta - \delta^2 > 0$ and $b\eta - \delta^2 > 0$,So the relationship between w_{sn}^{*} and λ_s 、 e^{*} and λ_s requires further analysis:

When $b\eta - \delta^2 > 0$, precisely when $\delta^2 < b\eta$, because b and η are constants higher than zero, so $2b\eta - \delta^2 > 0$, at this time $\frac{\partial w_{sn}^{*}}{\partial \lambda_s} > 0$, $\frac{\partial p_{sn}^{*}}{\partial \lambda_s} > 0$;

When $b\eta - \delta^2 < 0 < 2b\eta - \delta^2$, precisely when $b\eta < \delta^2 < 2b\eta$, $\frac{\partial w_{sn}^{*}}{\partial \lambda_s} > 0$, $\frac{\partial p_{sn}^{*}}{\partial \lambda_s} < 0$;

When $2b\eta - \delta^2 < 0 < 4b\eta - \delta^2$, precisely when $2b\eta < \delta^2 < 4b\eta$, $\frac{\partial w_{sn}^{*}}{\partial \lambda_s} < 0$, $\frac{\partial p_{sn}^{*}}{\partial \lambda_s} < 0$.

In summary, when $\delta^2 < 2b\eta$, $\frac{\partial w_{sn}^{*}}{\partial \lambda_s} > 0$; when $2b\eta < \delta^2 < 4b\eta$, $\frac{\partial w_{sn}^{*}}{\partial \lambda_s} < 0$; when $\delta^2 > b\eta$, $\frac{\partial p_{sn}^{*}}{\partial \lambda_s} < 0$; when $\delta^2 < b\eta$, $\frac{\partial p_{sn}^{*}}{\partial \lambda_s} > 0$.

Completed.

Conclusions 2 indicates that the retailer's selling price are influenced by the supplier fairness preference degree, increases with the increase of the supplier fairness preference when $\delta^2 < b\eta$, and decreases with the increase of the supplier's fairness preference when $\delta^2 > b\eta$; the supplier's wholesale price and carbon emission are influenced by his own fairness preference, carbon emission reduction reduces with the increase of his own fairness preference ; the supplier's wholesale price increases with the increasing of his fairness preference when $\delta^2 < 2b\eta$, and decreases with the increase of his fairness preference when $2b\eta < \delta^2 < 4b\eta$.

VII. Considering both the retailer and the supplier has fairness preference

When both the retailer and the supplier have fairness preference, their utility functions are respectively:

$$U_r = \left(1+\lambda_r\right)\pi_r - \frac{\lambda_r\left(1+\lambda_r\right)}{2+\lambda_r+\lambda_s}\pi$$
$$= (1+\lambda_r)(p-w)(a-bp+\delta e)$$
$$-\frac{\lambda_r(1+\lambda_r)}{2+\lambda_r}\left[(p-c)(a-bp+\delta e) - \frac{1}{2}\eta e^2\right]$$

$$U_s = \left(1+\lambda_s\right)\pi_s - \frac{\lambda_s\left(1+\lambda_s\right)}{2+\lambda_s+\lambda_r}\pi$$
$$= (1+\lambda_s)\left[(w-c)(a-bp+\delta e) - \frac{1}{2}\eta e^2\right]$$
$$-\frac{\lambda_s(1+\lambda_s)}{2+\lambda_s+\lambda_r}\left[(p-c)(a-bp+\delta e) - \frac{1}{2}\eta e^2\right]$$

Proposition 3: When the retailer and the supplier has fairness preference, their utility functions are strictly concave functions, and the optimal price p_{rn}^{*} of retailers drives U_r to obtain

a maximum value , the supplier's optimal wholesale price and optimal carbon emission w_{rn}^* and e_{rn}^* allow give the maximum value of U_s .

Proof: Let us find the first derivative and the second derivative of the U_r .

$$\frac{\partial^2 U_r}{\partial p^2}=\frac{-2b\lambda_r\lambda_s-4b\lambda_r-2b\lambda_s-4b}{2+\lambda_r+\lambda_s}<0$$

U_r is a strictly concave function, and the retailer has the optimal price when both the retailer and the supplier have fairness preference.

When $\frac{\partial U_r}{\partial p}=0$

$$p_{bn}=\frac{-bc\lambda_r+bw\lambda_r+bw\lambda_s+\delta e\lambda_s+a\lambda_s+2bw+2\delta e+2a}{2(\lambda_s+2)b} \quad (14)$$

Introduce (11) into U_s , the first derivative and the second derivative of U_s are as follows:

$$\frac{\partial^2 U_s}{\partial w^2}=\frac{b(\lambda_s{}^2+5\lambda_s+4)(2+\lambda_r+\lambda_s)}{-2(2+\lambda_s)^2}$$

$$\frac{\partial^2 U_s}{\partial e^2}=\frac{2b\eta\lambda_s\lambda_r+\delta^2\lambda_s{}^2+2b\eta\lambda_r+4b\eta\lambda_s+\delta^2\lambda_s+4b\eta}{-2(2+\lambda_s+\lambda_r)b}$$

$$\frac{\partial^2 U_s}{\partial w^2}<0,\ \frac{\partial^2 U_s}{\partial e^2}<0$$

In this case, U_s is a strictly concave function, and the supplier can get the optimal wholesale price as well as the optimal carbon emission reduction when both the retailer and the supplier have fairness preference.

Considering simultaneously $\frac{\partial U_s}{\partial w}=0$ and $\frac{\partial U_s}{\partial e}=0$, let us find the optimal wholesale price and the optimal carbon reduction of the supplier.

$$w_{bn}^*=(bc\eta\lambda_r{}^2\lambda_s+a\eta\lambda_r\lambda_s{}^2+4bc\eta\lambda_r{}^2$$

$$+4bc\eta\lambda_r\lambda_s+4a\eta\lambda_r\lambda_s+2a\eta\lambda_s{}^2+12bc\eta\lambda_r+4bc\eta\lambda_s$$

$$-2c\delta^2\lambda_r-2c\delta^2\lambda_s+4a\eta\lambda_r+8a\eta\lambda_s+8bc\eta-4c\delta^2$$

$$+8a\eta)\frac{1}{(2+\lambda_r+\lambda_s)(b\eta\lambda_r\lambda_s+4b\eta\lambda_r+2b\eta\lambda_s+8b\eta-2\delta^2)} \quad (15)$$

$$e_{bn}^*=\frac{2(a-bc)\delta}{b\eta\lambda_r\lambda_s+4b\eta\lambda_r+2b\eta\lambda_s+8b\eta-2\delta^2} \quad (16)$$

Introduce (15) (16) into (14)

$$p_{bn}^*=\frac{a\eta\lambda_r\lambda_s+bc\eta\lambda_r+3a\eta\lambda_r+2a\eta\lambda_s+2bc\eta-2c\delta^2+6a\eta}{b\eta\lambda_r\lambda_s+4b\eta\lambda_r+2b\eta\lambda_s+8b\eta-2\delta^2}$$

Completed

Conclusion 3: $\frac{\partial e_{bn}^*}{\partial\lambda_r}<0$, $\frac{\partial e_{bn}^*}{\partial\lambda_s}<0$.

Prove:

$$\frac{\partial e_{bn}^*}{\partial\lambda_r}=\frac{-2\delta(a-bc)(b\eta\lambda_s+4b\eta)}{(b\eta\lambda_r\lambda_s+4b\eta\lambda_r+2b\eta\lambda_s+8b\eta-2\delta^2)^2}$$

$$\frac{\partial e_{bn}^*}{\partial\lambda_s}=\frac{-2\delta(a-bc)(b\eta\lambda_r+2b\eta)}{(b\eta\lambda_r\lambda_s+4b\eta\lambda_r+2b\eta\lambda_s+8b\eta-2\delta^2)^2}$$

obviously $\frac{\partial e_{bn}^*}{\partial\lambda_r}<0$, $\frac{\partial e_{bn}^*}{\partial\lambda_s}<0$ 。

Certificate completed

Conclusions 3 indicates that when both the retailer and the supplier have fairness preference, the supplier's carbon emission reduction volume reduces with the increasing of the retailer's as well as his own fairness preference. It shows that when members of the supply chain have fairness preference, it happens a fierce game. Generally, in order to gain more profits, the supplier will reduce carbon emission reduction.

Conclusions4: when $\lambda_r>\frac{2\delta^2}{b\eta}-2$, $\frac{\partial p_{bn}^*}{\partial\lambda_s}>0$; when $\lambda_r<\frac{2\delta^2}{b\eta}-2$, $\frac{\partial p_{bn}^*}{\partial\lambda_s}<0$ and $\frac{\partial w_{bn}^*}{\lambda_s}>0$ 。

Prove:

$$\frac{\partial p_{bn}^*}{\partial\lambda_r}=\frac{-2\eta\delta^2(a-bc)(\lambda_s+3)}{(b\eta\lambda_r\lambda_s+4b\eta\lambda_r+2b\eta\lambda_s+8b\eta-2\delta^2)^2}$$

$$\frac{\partial w_{bn}^*}{\partial\lambda_r}=\frac{1}{(2+\lambda_r+\lambda_s)^2(b\eta\lambda_r\lambda_s+4b\eta\lambda_r+2b\eta\lambda_s+8b\eta-2\delta^2)^2}\cdot-\eta(a-bc)(b\lambda_r{}^2\lambda_s{}^3\eta$$

$$+8b\eta\lambda_r^2\lambda_s^2+4b\eta\lambda_r\lambda_s^3+20b\eta\lambda_r^2\lambda_s+32b\eta\lambda_r\lambda_s+4\lambda_s^3\eta+16b\eta\lambda_r^2+80b$$

$$+2\delta^2\lambda_s{}^3+32b\eta\lambda_s{}^2+8\delta^2\lambda_s{}^2+64b\eta\lambda_r+80b\eta\lambda_s+8\delta^2\lambda_s+64b\eta)$$

$$\frac{\partial p_{bn}^*}{\partial\lambda_r}<0,\ \frac{\partial w_{bn}^*}{\partial\lambda_r}<0$$

$$\frac{\partial p_{bn}^*}{\partial \lambda_s} = \frac{\eta(\lambda_r + 2)(a-bc)(b\eta\lambda_r + 2b\eta - 2\delta^2)}{\left(b\eta\lambda_r\lambda_s + 4b\eta\lambda_r + 2b\eta\lambda_s + 8b\eta - 2\delta^2\right)^2}$$

$$\frac{\partial w_{bn}^*}{\lambda_s} = \frac{(a-bc)\left[(b\eta\lambda_r + 2b\eta - 2\delta^2)A + B\right]}{(1+\lambda_r+\lambda_s)^2(b\eta\lambda_r\lambda_s + 4b\eta\lambda_r + 2b\eta\lambda_s + 8b\eta - 2\delta^2)^2}$$

$$A = 2\lambda_r^2\lambda_s + \lambda_r\lambda_s^2 + 4\lambda_r^2 + 8\lambda_r\lambda_s + 2\lambda_s^2 + 12\lambda_r + 8$$

$$B = b\eta(\lambda_r^3\lambda_s^2 + 6\lambda_r^3\lambda_s + 5\lambda_r^2\lambda_s^2 + 8\lambda_r^3 + 28\lambda_r^2\lambda_s + 8\lambda_r\lambda_s^2 + 36\lambda_r^2$$

$$+40\lambda_r\lambda_s + 4\lambda_s^2 + 48\lambda_r + 16\lambda_s + 16)$$

Since we cannot judge whether $b\eta\lambda_r + 2b\eta - 2\delta^2$ and $\left[(b\eta\lambda_r + 2b\eta - 2\delta^2)A + B\right]$ are positive or negative, we need to categorize the analysis. Firstly, let us examine the positive and negative cases for $b\eta\lambda_r + 2b\eta - 2\delta^2$

When $b\eta\lambda_r + 2b\eta - 2\delta^2 > 0$, precisely when $\lambda_r > \frac{2\delta^2}{b\eta} - 2$, since $a-bc$ is positive, so $\frac{\partial p_{bn}^*}{\partial \lambda_s} > 0$; when $b\eta\lambda_r + 2b\eta - 2\delta^2 < 0$, precisely when, $\frac{\partial p_{bn}^*}{\partial \lambda_s} < 0$;

Next we discuss $(b\eta\lambda_r + 2b\eta - 2\delta^2)A + B$:

When $(b\eta\lambda_r + 2b\eta - 2\delta^2)A + B = 0$, with $\lambda_r > 0$, we ignore the two negative values, $\lambda_r = \frac{-2b\eta\lambda_s - 8b\eta + 2\delta^2 + \sqrt{2b\delta^2\eta\lambda_s^2 + 8b\delta^2\eta\lambda_s + 16b^2\eta^2 - 8b\delta^2\eta + 4\delta^2}}{b\eta(\lambda_s + 6)}$, when $\lambda_r > \frac{-2b\eta\lambda_s - 8b\eta + 2\delta^2 + \sqrt{2b\delta^2\eta\lambda_s^2 + 8b\delta^2\eta\lambda_s + 16b^2\eta^2 - 8b\delta^2\eta + 4\delta^2}}{b\eta(\lambda_s + 6)}$, $\frac{\partial w_{bn}^*}{\lambda_s} > 0$;When $\lambda_r < \frac{-2b\eta\lambda_s - 8b\eta + 2\delta^2 + \sqrt{2b\delta^2\eta\lambda_s^2 + 8b\delta^2\eta\lambda_s + 16b^2\eta^2 - 8b\delta^2\eta + 4\delta^2}}{b\eta(\lambda_s + 6)}$, $\frac{\partial w_{bn}^*}{\lambda_s} < 0$ .But because when $\lambda_s > 0$, $\frac{-2b\eta\lambda_s - 8b\eta + 2\delta^2 + \sqrt{2b\delta^2\eta\lambda_s^2 + 8b\delta^2\eta\lambda_s + 16b^2\eta^2 - 8b\delta^2\eta + 4\delta^2}}{b\eta(\lambda_s + 6)} < 0$, and $\lambda_r > 0$,so $\lambda_r < \frac{-2b\eta\lambda_s - 8b\eta + 2\delta^2 + \sqrt{2b\delta^2\eta\lambda_s^2 + 8b\delta^2\eta\lambda_s + 16b^2\eta^2 - 8b\delta^2\eta + 4\delta^2}}{b\eta(\lambda_s + 6)}$ is untenable, $\lambda_r > \frac{-2b\eta\lambda_s - 8b\eta + 2\delta^2 + \sqrt{2b\delta^2\eta\lambda_s^2 + 8b\delta^2\eta\lambda_s + 16b^2\eta^2 - 8b\delta^2\eta + 4\delta^2}}{b\eta(\lambda_s + 6)}$ is then permanently tenable. So when $\lambda_r > 0$, $\lambda_s > 0$, $\frac{\partial w_{bn}^*}{\lambda_s} > 0$.

Completed.

Conclusions 4 indicates that the retailer's sales price is influenced by some parameters. It increases with the increase of supplier's fairness preference when $\lambda_r > \frac{2\delta^2}{b\eta} - 2$, and reduces with the increase of supplier's fairness preference when $\lambda_r < \frac{2\delta^2}{b\eta} - 2$; the supplier's wholesale price reduces with the increase of retailer's fairness preference, and increases with the increase of his own fairness preference.

VIII. NUMERICAL SIMULATION

In order to discuss the model and illustrate more clearly the results, we will use a numerical example to analyze the results of the optimal decision in this section. Suppose $a = 300$, $b = 10$, $\delta = 5$, $c = 4$, $\eta = 2$. We introduce these parameters into the above model, and through Maple software obtain the optimal decisions.

Using the given parameters, let us firstly simulate the retailer having fairness preference. The retailer's level of fairness preference would impact the supplier's carbon emission reduction,

wholesale price and the retailer's sales price. As shown in Figure 1:

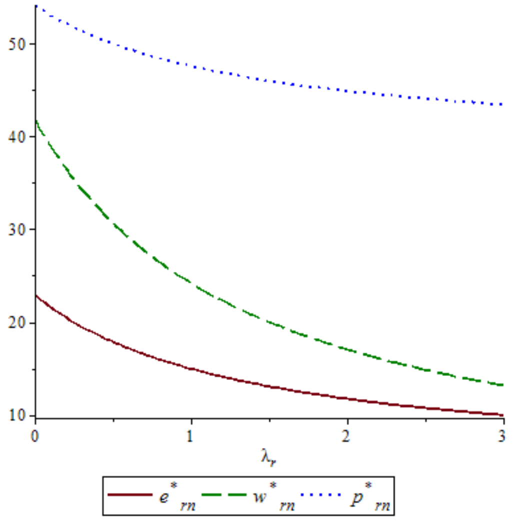

Figure 1:The relationship between carbon emission reduction, wholesale price, sales price and the fairness preference of the retailer

Figure 1 shows that the supplier's carbon emission reductions, wholesale prices and retail price reduce with the increase of the retailer's level of fairness preference. As well, with the increase of the level of fairness preference, the supplier's carbon emission reduction, wholesale price and retail price reduction trends tend to slow. It shows that with the increase of the degree of retailer's fairness preference, the supplier will reduce the wholesale price to meet the requirements of the retailer's profit, and reduce his own carbon emission to save costs.

When the supplier has fairness preference, the supplier's degree of fairness will impact the supplier's carbon emission reduction, wholesale price and the retailer's sales price. Since b , η , δ will impact the supplier's wholesale price, the retailer's sales price and the level of the supplier's fairness preference, I assume that b and η values do not change , consider δ equal to 5,4 and 7. When $\delta = 5$, $b\eta - \delta^2 < 0 < 2b\eta - \delta^2$ and $\frac{\partial w_{sn}^*}{\partial \lambda_s} > 0$ and $\frac{\partial p_{sn}^*}{\partial \lambda_s} < 0$, results are as shown in Figure 2; when $\delta = 4$, $b\eta - \delta^2 > 0$ and $\frac{\partial w_{sn}^*}{\partial \lambda_s} > 0$ and $\frac{\partial p_{sn}^*}{\partial \lambda_s} > 0$, results are in Figure 3;

Figure 4 shows when $\delta = 7$, $2b\eta - \delta^2 < 0 < 4b\eta - \delta^2$ and $\frac{\partial w_{sn}^*}{\partial \lambda_s} < 0$ and $\frac{\partial p_{sn}^*}{\partial \lambda_s} < 0$;

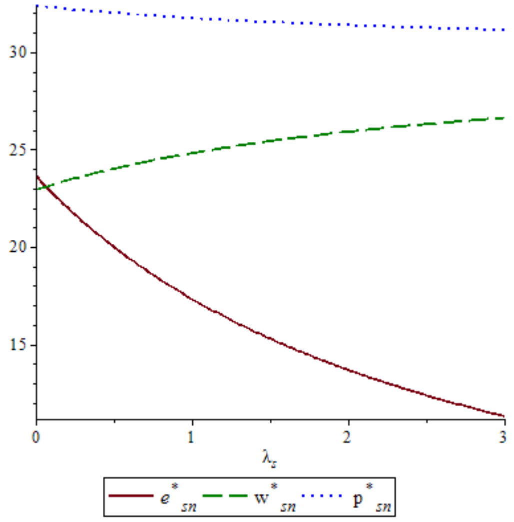

Figure 2: The relationship between carbon emission reduction, wholesale price, sales price and the degree of fairness preference of suppliers ($b\eta - \delta^2 < 0 < 2b\eta - \delta^2$)

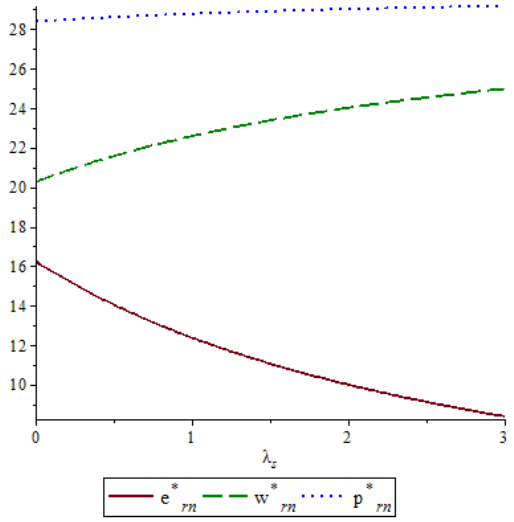

Figure 3: The relationship between carbon emission reductions, wholesale prices, sales price and the degree of fairness preference of suppliers ($b\eta - \delta^2 > 0$)

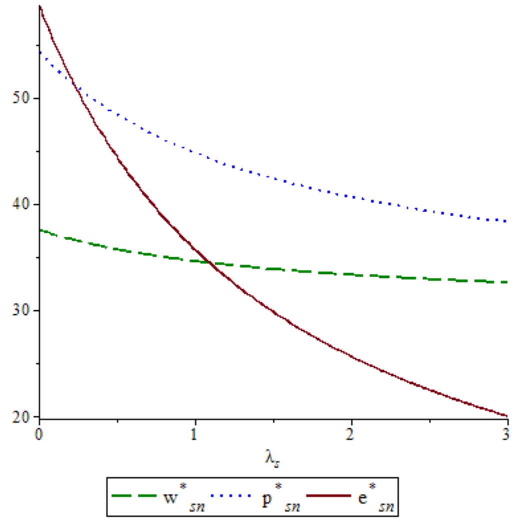

Figure 4: The relationship between carbon emission reductions, wholesale prices, sales price and the degree of fairness preference of suppliers ($2b\eta-\delta^2<0<4b\eta-\delta^2$)

Figure 2 shows that both the retailer's sales price and the supplier's carbon emission reduction decrease with the increase of the supplier's fairness preference, and the supplier's wholesale price increases with the increase of his fairness preference. Figure 2 also shows that when the supplier has fairness preference, the supplier may increase the wholesale price and reduce carbon emission reductions to get more profit. Besides, it can be seen from figure 2 that when the supplier has fairness preference, the decline of the supplier's carbon emission reduction is more rapid than the increase of the supplier's wholesale price , indicating that in order to get more profit, the supplier will reduce carbon emission reductions, meaning reduce costs rather than raising wholesale prices.

Figure 3 shows that both the retailer's sales price and the supplier's wholesale price increase with the increase of the supplier's fairness preference, and the supplier's carbon emission reduction decreases with the increase of his own fairness preference. We can also figure out that with the increase of supplier's fairness preference, the increasing rate of the wholesale price is higher than that of the retailer's sales price, the trend of the supplier's carbon emission reduction lowers as well with the increase of the supplier's fairness preference degree. It means that when his fairness preference grows, the supplier may try to get more profit by reducing carbon emissions cost and raising the wholesale price.

Figure 4 shows that both the retailer's sales price, the supplier's carbon emission reduction and the wholesale price decrease with the increase of the supplier's fairness preference. It can also be seen from the figure that carbon emission reduction is very remarkable, indicating that the supplier in order to obtain a higher profit will drastically reduce carbon emission reduction.

When retailers and suppliers both have fairness preference, the retailer's and the supplier's level of fairness would impact the supplier's carbon emission reductions, the wholesale price and the retailer's sales price . As shown in Figure 5,6,7and 8:

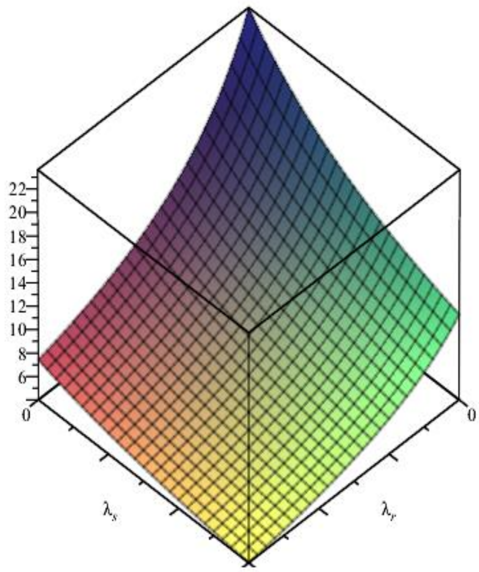

Figure 5:The relationship between carbon emission reductions and the degree of fairness preference of suppliers and retailers

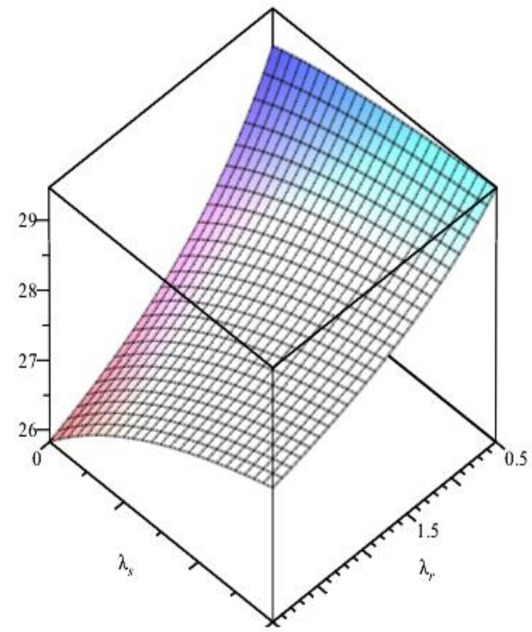

Figure 6:The relationship between the sales price and the degree of fairness preference of the suppliers and retailers ($\lambda_r > \frac{2\delta^2}{b\eta} - 2$)

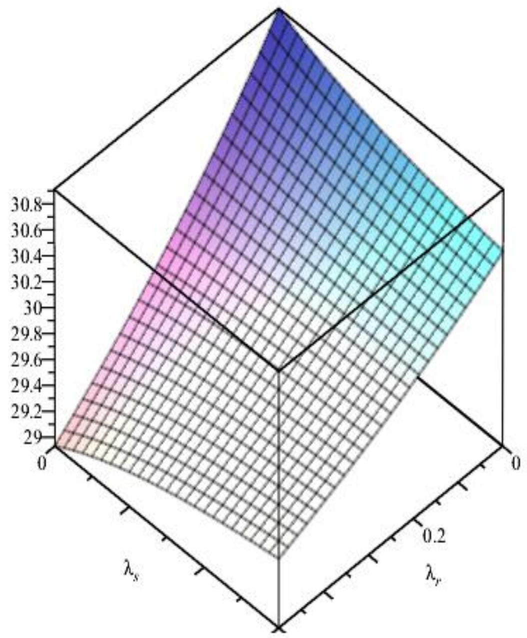

Figure 7: The relationship between the sales price and the degree of fairness preference of the suppliers and retailers ($\lambda_r < \frac{2\delta^2}{b\eta} - 2$)

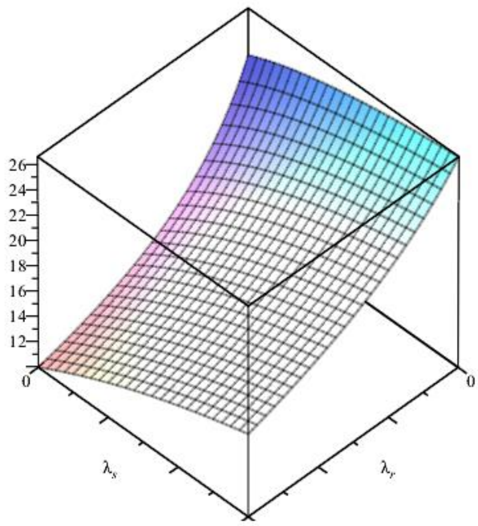

Figure 8:The relationship between wholesale price and the degree of fairness preference of the suppliers and retailers

Figure 5 shows that the supplier's carbon emissions reduction trend decreases with the increase of fairness preference degree of the supplier and the retailer; From figure 6 and Figure 7, we can find out that the retailer's sales price will change if the level of the retailer's fairness preference changes. When the retailer's fairness preference is $\lambda_r < \frac{2\delta^2}{b\eta} - 2$, it is obvious that the sales price decreases with the increase of the supplier's fairness preference degree (λ_r is unchanged) ; and when the retailer's fairness preference is $\lambda_r > \frac{2\delta^2}{b\eta} - 2$, the retailer's sales price increases with the increase of the supplier's fairness preference. From Figure 8, we can figure out that the supplier's wholesale price increases with the increase of the fairness preference degree of the retailer and the supplier.

IX. CONCLUSION

Under linear demand condition, this paper applies Nash bargaining game theory to build a fairness concern framework, analyze the effect of fairness preference on retailer's sales prices , the supplier's carbon emission reduction and wholesale price by building models and carrying out case studies. The aim of these studies is to find out the optimal decision that are accurate in

the following three situations: the retailer has fairness preference, the supplier has fairness preference, and both the retailer and the supplier have fairness preference. Results show that under linear demand constraints, when the supply chain members have fairness preference, the trend of supplier's carbon emission reduction decreases with increase of the degree of fairness preference, that is to say, in the game between the supplier and the retailer, the supplier will not actively carry out carbon emissions reduction. When the retailer has fairness preference and the supplier does not, the retailer's sales price and the supplier's wholesale price will reduce with the increase of the retailer's degree of fairness concern. It shows that when the retailer has fairness concern, the supplier will reduce the wholesale price to transfer profits,and at the same time lowers his carbon emission reduction to reduce expenses while the retailer would lower his sales price to ensure fair profit distribution among the supply chain members. When the supplier has fairness preference and the retailer does not, the retailer's sales price, the supplier's wholesale price and the degree of the supplier's fairness preference are subjected to the influence of the retailer's sales price coefficient, the supplier's carbon emission reduction coefficient and the carbon emission reduction cost coefficient. When retailer and supplier both have fairness preferences, the retailer's sales price is influenced by his own degree of fairness preference, the supplier's wholesale price decreases with the increase of the retailer's fairness preference degree and increases with the increase of his own fairness preference degree.

However, this article has many limitations. The subject of this paper is a two-echelon supply chain consisting of one supplier and one retailer, what can be extended to a multi-echelon supply chain in the future. Moreover, under different carbon policy, studying the problem of supply chain decisions considering fairness preference is a future direction for researches.

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